

**GMAO RESEARCH BRIEF**

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Korea-United States Air Quality (KORUS-AQ) Campaign

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SUMMARY

The Korea-United States Air Quality (KORUS-AQ) campaign was an international cooperative field study based out of Osan Air Base, Songtan, South Korea (about 60 kilometers south of Seoul) in April-June 2016. A comprehensive suite of instruments capable of measuring atmospheric composition was deployed around the Korean peninsula on aircrafts, ships, and at ground sites in order to characterize local and transboundary pollution. The NASA Goddard Earth Observing System, version 5 (GEOS-5) forecast model was used for near real time meteorological and aerosol forecasting and flight planning during the KORUS-AQ campaign. Evaluation of GEOS-5 against observations from the campaign will help to identify inaccuracies in the model's physical and chemical processes in this region within East Asia and lead to further developments of the modeling system.

BACKGROUND

Air quality is a fundamental concern across the globe. In South Korea, roughly half the population is located within the Seoul Capital Area, where high levels of ozone (O_3), fine particles (i.e., $PM_{2.5}$), and other toxic pollutants are routinely observed. The goal of the KORUS-AQ campaign was to gain a better understanding of the factors controlling air quality over the Korean peninsula and the surrounding waters by (1) determining the relative importance of human and natural emissions on O_3 and aerosol formation, and (2) characterizing the composition and chemistry of local and trans-boundary pollution from mainland China. In addition, KORUS-AQ was meant to be a model of international collaboration that contributes to both the scientific understanding and community building needed to ensure the success of the constellation of geostationary satellites for atmospheric composition to be launched over the next decade.

In recent years, it has been demonstrated that satellite instruments in low Earth orbit (LEO) have the ability to measure the atmospheric composition of key species affecting air quality such as nitrogen dioxide (NO_2), O_3 , and aerosols. The broad spatial coverage afforded from space has allowed these instruments to provide climate data records of global air quality, and fill the gaps between ground-based observation sites. However, the infrequent sampling and coarse resolution of current LEO satellite instruments are insufficient to monitor air quality events in detail. Therefore, an international effort to launch a geostationary constellation of satellite instruments focused on air quality was developed.

Satellite instruments in geostationary orbit (GEO) can provide measurements many times throughout the day and at higher spatial resolution by taking advantage of longer viewing times. To date, GEO satellites have been used for communications and meteorological observations, but over the next few years a constellation of GEO satellites specifically to observe atmospheric composition will be launched. The planned geostationary constellation is comprised of three satellites over the Northern Hemisphere: GEMS (Geostationary Environmental Monitoring Spectrometer) over Asia, Sentinel-4 over Europe, and TEMPO (Tropospheric Emissions: Monitoring Pollution) over North America (Figure 1). These satellites will provide hourly observations at spatial resolutions of better than 10 km. A constellation of GEO satellite instruments will overcome the limited viewing domain of the geostationary vantage point. However, developing strong international collaborative relationships between the satellite instrument teams will be key to enabling a truly integrated view between these satellites.

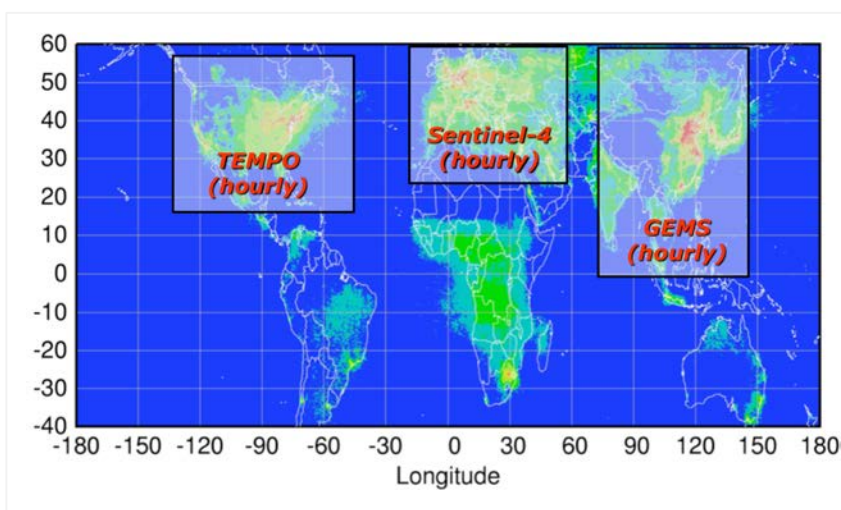


Figure 1. Spatial coverage of the proposed air quality geostationary constellation. The background image is the global distribution of NO_2 as seen from space.

Components of KORUS-AQ

To meet the science goals of the campaign, observations from three platforms –satellites, ground sites, and aircraft – each providing a unique perspective of atmospheric composition, were integrated with air quality models (Figure 2): (1) satellites provide broad coverage and daily observations, although these observations have limited near-surface information; (2) ground sites are the primary method for continuous surface monitoring (at hourly or better temporal resolution), however the spatial coverage is limited; and (3) airborne sampling provides short-term observations, which enables us to connect ground-based and satellite observations. The aircrafts flown during KORUS-AQ (Figure 2) carried an extensive instrument payload, which can provide multiple, collocated observations capable of identifying and disentangling the contributions of different primary emission sources to secondary pollutant formation. Combining observations from all three perspectives with regional and global models can inform and improve our understanding of the physical and chemical processes that drive air quality in the region.

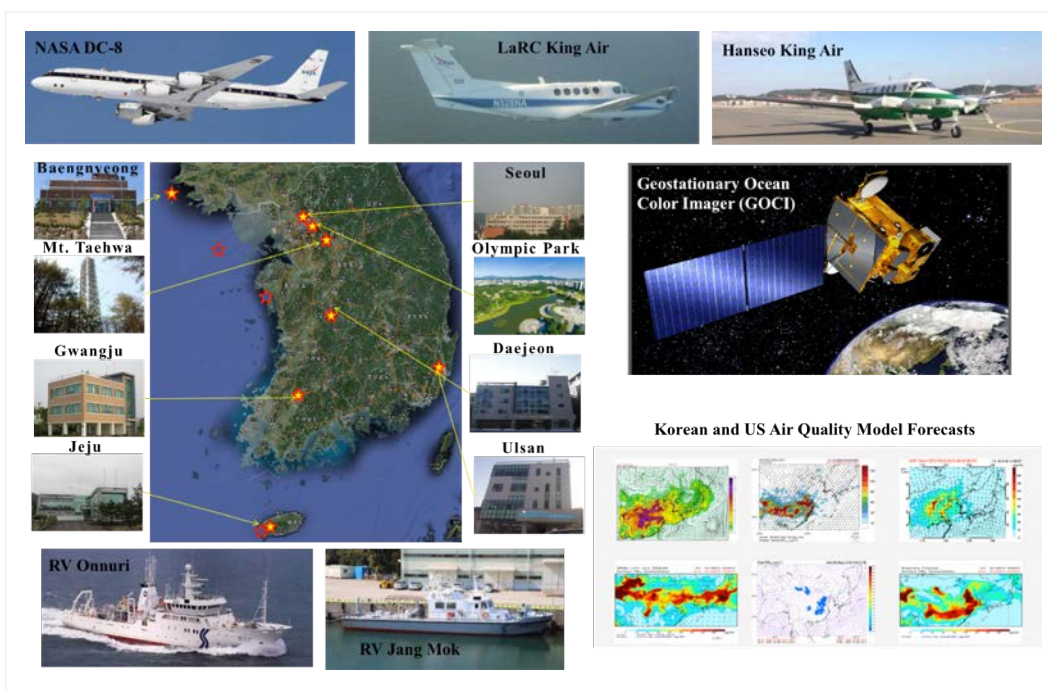


Figure 2. Overview of the observation and modeling components of the KORUS-AQ campaign.

Korea-United States Ocean Color expedition (KORUS-OC) occurred concurrently with KORUS-AQ, and extended observations to Korea's surrounding waters. Several aircraft overpasses of KORUS-OC ships were coordinated during the campaigns, which will enable evaluation of the effects of atmospheric concentrations of NO_2 , O_3 , and aerosols on satellite retrievals of ocean color.

Aircraft Observations

The NASA DC-8 (Figure 2) carried 25 instruments, five of which were from Korean investigators. These instruments provided detailed observations of trace gas and aerosol atmospheric composition. The NASA LaRC King Air (Figure 2) carried Geo-TASO, a satellite instrument simulator for TEMPO. This optical sensor measures backscattered light analogous to the type of measurements that will be made by geostationary instruments. The Korean aircraft, the Hanseo King Air (Figure 2), carried a smaller payload measuring O_3 , PM, NO_2 , CH_2O , SO_2 , and CO, with the CH_2O provided by NASA Goddard Space Flight Center (GSFC).

Surface Observations

There are more than 300 air-quality ground-based monitoring sites around the Korean peninsula operated by the Korean National Institute for Environmental Research (NIER). NASA provided additional instruments at eight of these sites (Figure 2), including ground based remote sensing of aerosol and trace gases (aerosol robotic network, AERONET and Pandora), ground based lidars for aerosols and O_3 , and ozonesondes. The KORUS-OC ships extended in situ observations of aerosol and trace gases to the surrounding waters.

Satellite Observations

While the current constellation of LEO satellites such as MODIS and OMI contributed key atmospheric composition observations once or twice per day, the Korean peninsula had the added advantage of being covered by the world's first GEO instrument for measuring ocean color and atmospheric aerosol. Thus, KORUS-AQ provides a unique opportunity to prototype aerosol data assimilation and forecasting algorithms with this new type of high-resolution data.

GEOS-5 and the Multi-Model Aerosol and Weather Forecast

GEOS-5 aerosol forecasts were used daily for flight planning during the KORUS-AQ mission. Flight plans were drawn up from a consensus forecast of GEOS-5 and other modeling systems from partner U.S and Korean institutions. Figure 3 shows the 60-hr aerosol optical depth (AOD) forecast from four modeling systems including GEOS-5 for 25 May 2016. The forecasts from these models suggest an inflow of pollution from China over the Yellow Sea for this flight day.

On the morning of the 25 May 2016, the updated GEOS-5 12-hr forecast indicated an intensification of the pollution inflow from China compared to the 60-hr forecast (Figure 4). AOD values above 1.0 (warm colors) were forecasted over the Yellow Sea, related to

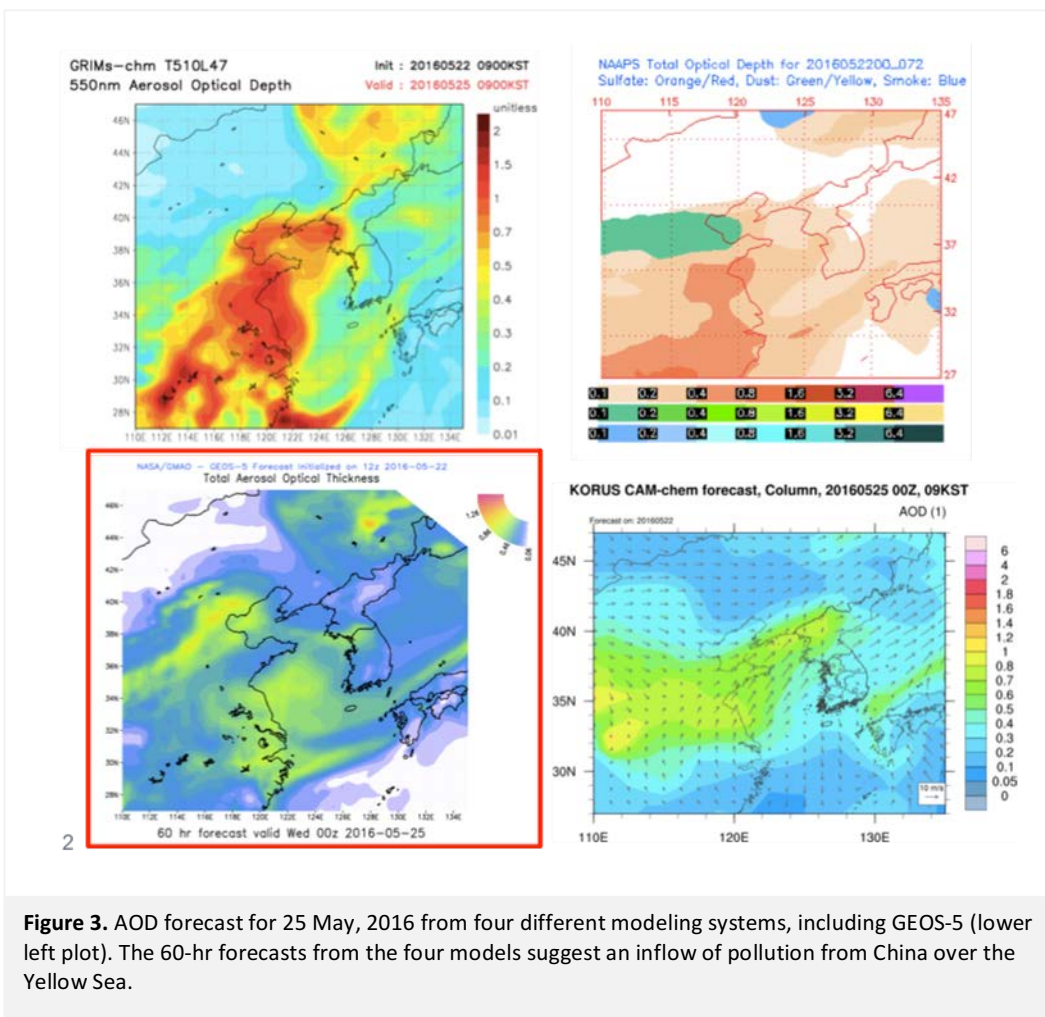


Figure 3. AOD forecast for 25 May, 2016 from four different modeling systems, including GEOS-5 (lower left plot). The 60-hr forecasts from the four models suggest an inflow of pollution from China over the Yellow Sea.

strong easterly wind flow (Figure 5). The indications of the revised forecast supported the flight planning decision to sample the full North-South extent of the Korean air space over the Yellow Sea (Figure 5 and red dashed line shown in Figure 4), a decision that yielded a key dataset of the chemical profile of highly polluted Chinese outflow during the strongest pollution episode of the campaign. Data from this flight will help constrain the production mechanism of secondary organic aerosols, as well as dust emissions and settling velocities.

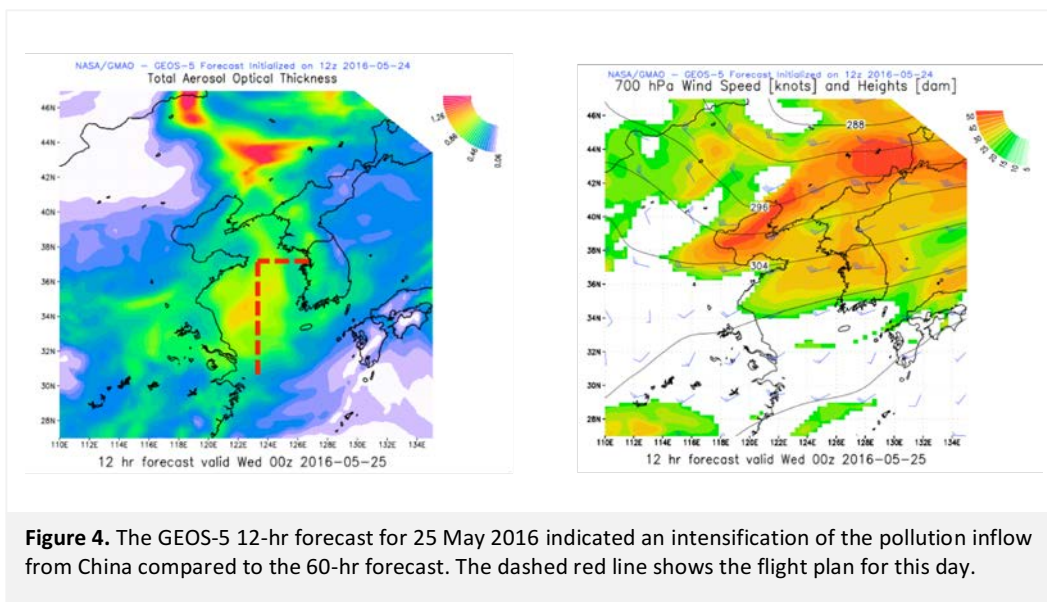


Figure 6 shows aerosol backscatter and depolarization ratio at 532 nm observed on 25 May 2016 by the DIAL-HSRL instrument onboard NASA's DC-8 and calculated from the GEOS-5 aerosol analysis sampled along the aircraft flight track. The high values of backscatter and low values of depolarization ratio below 2 km are an indication of small spherical particles originating from urban/industrial sources. At 3–5 km, high depolarization ratios in the observations indicate the presence of dust. Overall the GEOS-5 data assimilation results reproduced the general characteristics of the vertical column of the atmosphere, although GEOS-5 underestimates the intensity of the depolarization by the elevated dust layer.

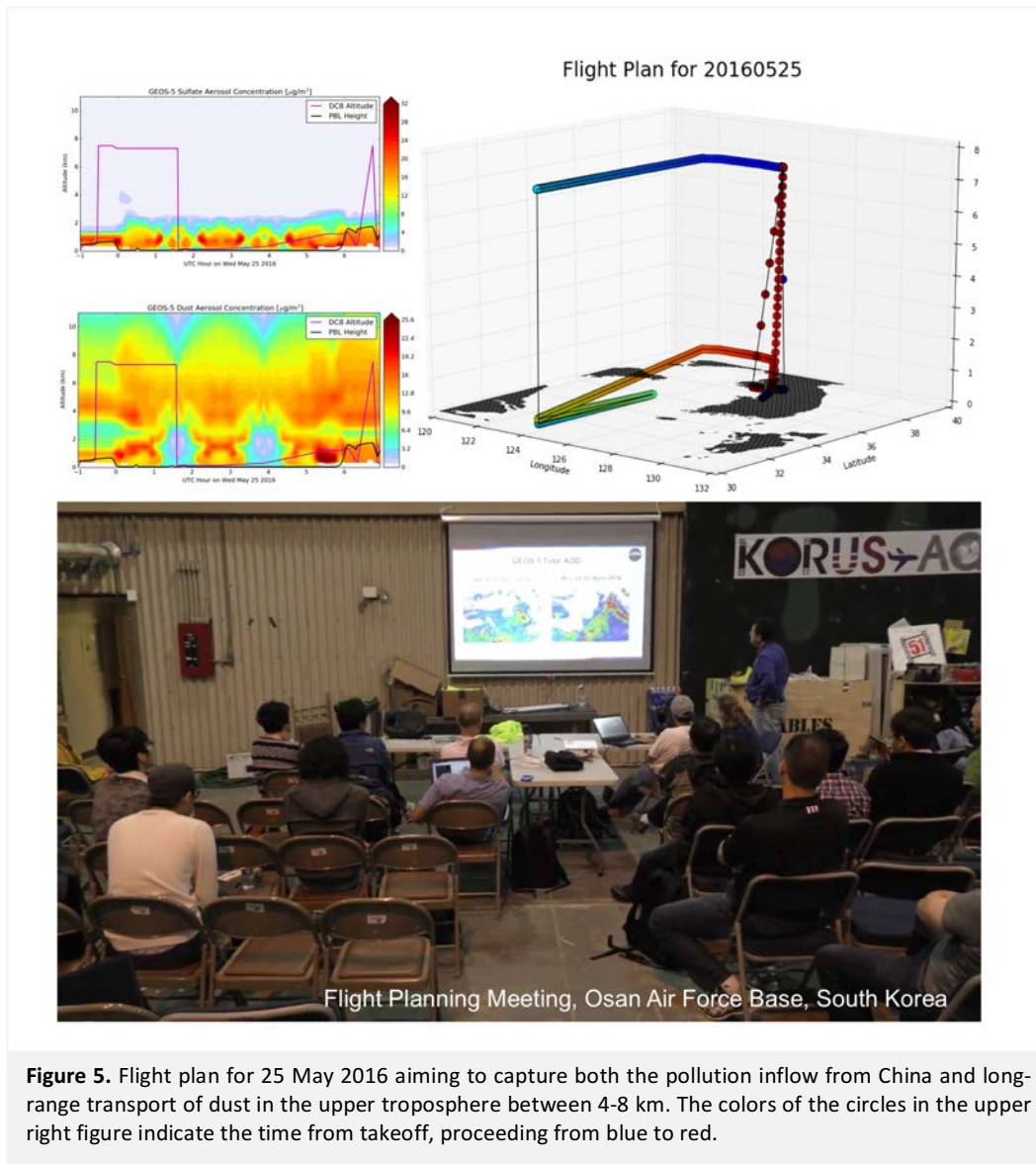
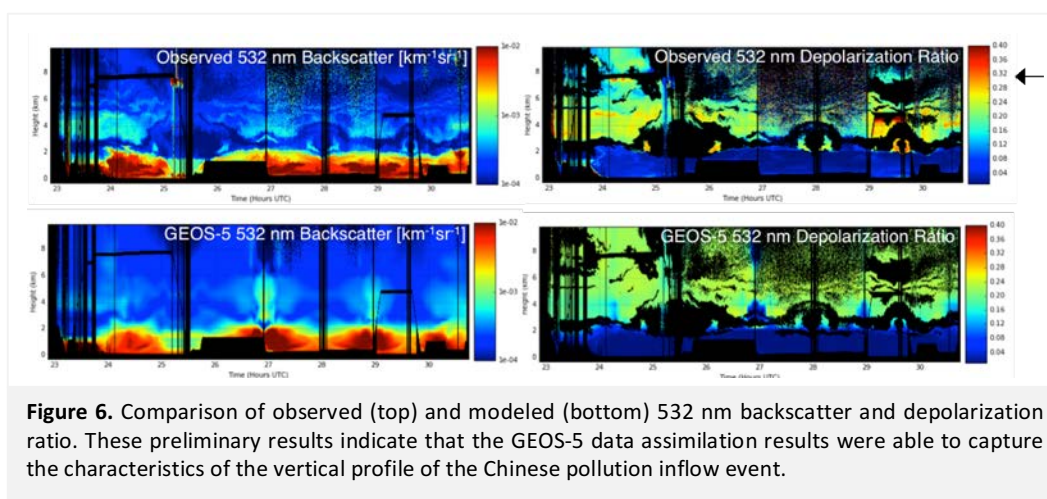


Figure 5. Flight plan for 25 May 2016 aiming to capture both the pollution inflow from China and long-range transport of dust in the upper troposphere between 4-8 km. The colors of the circles in the upper right figure indicate the time from takeoff, proceeding from blue to red.



In summary, the GEOS-5 operational forecast model played an integral role in the execution of the KORUS-AQ campaign. Post-mission, AOD observations derived from AERONET ground-based measurements and NASA satellite measurements will be assimilated into GEOS-5 to provide 4-dimensional meteorological and aerosol assimilated fields for use by KORUS-AQ instrument teams. Additionally, GMAO will perform a global 12-km full-chemistry simulation for the KORUS-AQ three-month time period based on the recent on-line implementation of the GEOS-CHEM chemical mechanism within GEOS-5. Evaluation of GEOS-5 against observations from the campaign will help to identify inaccuracies in the model's physical and chemical processes in the region and lead to further developments of the modeling system.

Chemical Acronyms

O₃ – Ozone

PM – Particulate Matter

NO₂ – Nitrogen Dioxide

CH₂O – Formaldehyde

SO₂ – Sulfur Dioxide

CO – Carbon Monoxide